Fermilab

Electrical Engineering Department --MS#222
Wilson Hall 14th Floor

To: Rick Ford, Bill Marsh

From: Craig Drennan

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Re: Establishing and maintaining the MiniBoone Target BPM Calibration.

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1. Introduction

We have developed new readout electronics for Beam Position Monitors to be used for the MiniBoone experiment. The readouts will only be used on the four BPM's nearest the target. Two of the BPM's and their readout electronics are installed spares. The scheme is to demodulate the RF signals from each channel of a BPM and then digitize the demodulated signals using the 10 MSPS "Quicker Digitizer" available in the IRM, Internet Rack Monitor networked DAQ chassis. The beam position is computed as

$$Pos\,(mm) = S_x \cdot \frac{m_1 \cdot \sum_{i=1}^{npts} A_i - \sum_{i=1}^{npts} B_i + (npts)\cdot(m_2 - m_3)}{m_1 \cdot \sum_{i=1}^{npts} A_i + \sum_{i=1}^{npts} B_i + (npts)\cdot(m_2 + m_3)} \qquad \text{Eq. 1.1}$$

where,

S_x is the BPM Sensitivity value, 30.842.

$npts$ is the number of samples of the A and B channels.

$A_i,\ i = 1 \ldots npts$ Are the channel A data sample values.

$B_i,\ i = 1 \ldots npts$ Are the channel B data sample values

m_1, m_2, m_3 Are the calibration coefficients.

This note describes the method with which the calibration coefficients are determined initially and are adjusted or re-determined when the channel A and / or the channel B electronics are replaced.

2. The BPM Readout Transfer Function and the Position Computation

The transfer function that describes how each channels voltage at the output of the synchronous demodulator relates to the voltage developed at the plate of the BPM is illustrated in Fig. 2.1. The system is assumed to be linear.

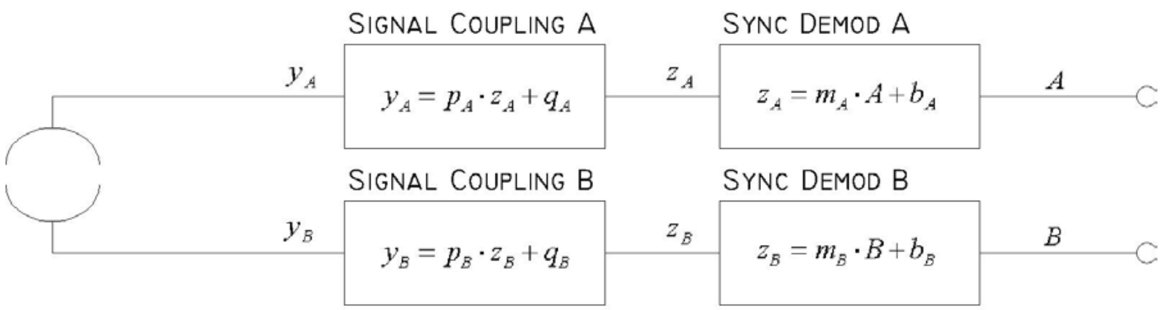

Fig. 2.1

The relationships in Fig. 2.1 are backwards from what is normally considered in that the equations compute the input given the output. In the end, it is the signal amplitudes at the BPM that are used to compute position.

$$P(mm) = S_x \cdot \frac{y_A - y_B}{y_A + y_B} \qquad \text{Eq. 2.1}$$

Since the digitizer gives more than one position sample per pulse we can determine the center of mass of all the sampled positions by weighting each according to the beam intensity at the instance the sample was taken, Eq. 2.2. The beam intensity is directly proportional to the sum of the two channels.

$$P_{cm}(mm) = \frac{\sum_{i=1}^{npts} P_i \cdot \left(y_{A\,i} + y_{B\,i}\right)}{\sum_{i=1}^{npts} \left(y_{A\,i} + y_{B\,i}\right)} \qquad \text{Eq. 2.2}$$

Substituting in for P_i we get Eq. 2.3. Further simplification leads to Eq. 2.4.

$$P_{cm}(mm) = \frac{\sum_{i=1}^{npts} S_x \cdot \frac{(y_{Ai} - y_{Bi})}{(y_{Ai} + y_{Bi})} \cdot (y_{Ai} + y_{Bi})}{\sum_{i=1}^{npts} (y_{Ai} + y_{Bi})} \qquad \text{Eq. 2.3}$$

$$P_{cm}(mm) = S_x \cdot \frac{\sum_{i=1}^{npts} y_{Ai} - \sum_{i=1}^{npts} y_{Bi}}{\sum_{i=1}^{npts} y_{Ai} + \sum_{i=1}^{npts} y_{Bi}} \qquad \text{Eq. 2.4}$$

The combined expressions relating the output of the BPM detector plates and the output of the synchronous demodulators are

$$\begin{aligned} y_A &= (p_A \cdot m_A) \cdot A + (p_A \cdot b_A + q_A) \\ y_B &= (p_B \cdot m_B) \cdot B + (p_B \cdot b_B + q_B) \end{aligned} \qquad \text{Eq. 2.5}$$

By substituting the expressions for y_A and y_B into Eq. 2.4 and dividing both the numerator and denominator by $(p_B \cdot m_B)$ we get the following expression for position

$$P_{cm}(mm) = S_x \cdot \frac{m_1 \cdot \sum_{i=1}^{npts} A_i - \sum_{i=1}^{npts} B_i + (npts) \cdot (m_2 - m_3)}{m_1 \cdot \sum_{i=1}^{npts} A_i + \sum_{i=1}^{npts} B_i + (npts) \cdot (m_2 + m_3)} \qquad \text{Eq. 2.6}$$

where *the **calibration coefficients*** are,

$$m_1 = \frac{p_A}{p_B} \cdot \frac{m_A}{m_B}, \quad m_2 = \frac{p_A \cdot b_A + q_A}{p_B \cdot m_B}, \quad m_3 = \frac{p_B \cdot b_B + q_B}{p_B \cdot m_B} \qquad \text{Eq. 2.7}$$

3. Initial Calculation of the Calibration Coefficients

The calibration coefficients consist of the gains and offsets imposed by the Synchronous Demodulators (m_A, m_B, b_A, b_B), and gains and offsets imposed by the signal coupling (p_A, p_B, q_A, q_B). The signal coupling includes a variety of effects on the beam position measurement, including the offset in the electrical center of the detector, and attenuation mismatches in the connecting cables and connectors. The gains and offsets of the Synchronous Demodulators are determined on the bench before installation. It is difficult to determine those associated with the signal coupling. We will assume that the signal coupling effects will remain the same for a long period of time. We will however measure the transfer characteristics of the cabling and connections as best we can with a network analyzer and use these as a benchmark.

For the MiniBoone Target BPMs we will collect data to determine the calibration coefficients directly. This will be done by temporarily installing a wire chamber to provide an independent measure of the beam position. The wire chamber can provide an accurate measure of the beam position, but it has the disadvantage of causing scattering of the beam past it and would soon burn up in the presence of the high intensity beam that is going to be used.

When beam is present the wire chamber center of mass position and the channel A and B sums will be recorded and used in the multiple regression described below to determine the calibration coefficients. Eq. 2.6 is rearranged as

$$\sum_{i=1}^{npts} B_i \cdot \left(1+\frac{P_{cm}}{S_x}\right) = m_1 \cdot \sum_{i=1}^{npts} A_i \cdot \left(1-\frac{P_{cm}}{S_x}\right) + m_2 \cdot (npts) \cdot \left(1-\frac{P_{cm}}{S_x}\right) - m_3 \cdot (npts) \cdot \left(1+\frac{P_{cm}}{S_x}\right) \qquad \text{Eq. 3.1}$$

This equation is in the form

$$Y = m_1 \cdot X_1 + m_2 \cdot X_2 + m_3 \cdot X_3$$

This is a form we can use to perform the multiple regression to determine m_1, m_2, m_3.

4. Re-Calculation of the Calibration Coefficients

If one of the Synchronous Demodulators needs to be replaced there needs to be a way of recalculating the calibration coefficients given that the new demodulator has a slightly different gain and offset (m_A, b_A or m_B, b_B). The definition of the calibration coefficients in Eq. 2.7 can be rewritten as in Eq. 3.2.

$$\begin{aligned} m_1 &= H_1 \cdot \frac{m_A}{m_B} \\ m_2 &= H_1 \cdot \frac{b_A}{m_B} + H_2 \cdot \frac{1}{m_B} \\ m_3 &= \frac{b_B}{m_B} + H_3 \cdot \frac{1}{m_B} \end{aligned} \qquad \text{Eq. 3.2}$$

Where,

$$H_1 = \frac{p_A}{p_B}, \quad H_2 = \frac{q_A}{p_B}, \quad H_3 = \frac{q_B}{p_B}$$

The H-variables are define by the gain and offset parameters of the signal coupling which we assume remain the same when a demodulator is replaced. After the initial determination of the calibration coefficients using the wire chamber data we can benchmark the H-variables. The H-variables are computed as in Eq. 3.3 below.

$$H_1 = m_1 \cdot \frac{m_B}{m_A}$$
$$H_2 = m_B \cdot \left(m_2 - m_1 \cdot \frac{b_A}{m_A} \right) \qquad \text{Eq. 3.3}$$
$$H_3 = m_B \cdot m_3 - b_B$$

Therefore, after replacing a demodulator module the new calibration coefficients are computed from the gains and offsets of the demodulators now in use and the H-variables established during the initial calibration, as in Eq. 3.2.